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Drought Indicators and Triggers

by

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Abstract

Effective drought management depends on drought indicators and triggers. Drought indicators are variables to detect and characterize drought conditions. Drought triggers are indicator thresholds to define and activate levels of drought responses. The complexity of drought, however, creates challenges in determining indicators and triggers and using them in a drought management plan. For instance, many indicators lack spatial and temporal consistency, statistical comparability with other indicators, and direct relevance to decision-making. This chapter seeks to provide needed clarity and guidance through three main sections. The first reviews common indicators and triggers, their functions, and their strengths and limitations. The second examines typical problems with indicators and triggers in drought plans, and offers a solution that transforms all indicators, triggers, and drought levels to percentiles. The third provides criteria for developing and evaluating indicators and triggers, and recommendations for using them in a drought plan.

I. Overview of Indicators and Triggers

Drought indicators are variables to describe the magnitude, duration, severity, and spatial extent of drought. Typical indicators are based on meteorological and hydrological variables, such as precipitation, streamflows, soil moisture, reservoir storage, and groundwater levels. Several indicators can be also synthesized into a single indicator on a quantitative scale, often called a drought index. Although drought indices (indexes) can provide ease of implementation, the scientific and operational meaning of an index value may raise questions; such as how each indicator is combined and weighted in the index, and how an arbitrary index value relates to geophysical and statistical characteristics of drought.

Drought triggers are threshold values of an indicator that distinguish a drought level, and determine when management actions should begin and end. Triggers ideally specify the indicator value, the time period, the spatial scale, the drought level, and whether progressing or receding conditions. Drought levels (phases, stages) are categories of drought, with nomenclature such as "mild, moderate, severe, extreme drought," or "stage 1, stage 2, stage 3 drought."

Drought indicators and triggers are important for several reasons: to detect and monitor drought conditions; to determine the timing and level of drought responses; and to characterize and compare drought events. Operationally, they form the linchpin of a drought management plan, tying together levels of drought severity with drought responses.

Even though drought has more than 150 published definitions (Wilhite and Glantz, 1985), one theme emerges: Drought is a condition of insufficient water to meet needs (Redmond, 2002). Water needs, as well as water supplies, can differ depending on context, and thus the characterization of drought can require different indicators and quantifications for triggers. The most common are related to meteorological and hydrological water availability and uses (Wilhite and Glantz, 1985; Byun and Wilhite, 1999; Heim, 2002).

Meteorological drought indicators are associated with climatological variables such as precipitation, temperature, and evapotranspiration. Meteorological indices include the Palmer Drought Severity Index (PDSI) (Palmer, 1965), Deciles (Gibbs and Maher, 1967), and the Standardized Precipitation Index (SPI) (McKee et al., 1993). Precipitation is a widely used and useful indicator; it can provide a direct measurement of water supplies, it influences hydrological indicators, and it can reflect drought impacts over different time periods and sectors. Yet meteorologic indicators, such as precipitation, can pose analytic challenges due to temporal and spatial variability, lack of data, and insufficient observation stations. Regarding indices, the PDSI has been one of the most widely used in the U.S., even though the SPI has advantages of statistical consistency, and ability to reflect both short-term and long-term drought impacts (Guttman, 1998; Hayes et al. 1999). An evaluation of common indicators, according to six criteria of performance, indicates strengths of the SPI and Deciles over the PDSI (Keyantash and Dracup, 2002).

Hydrological drought indicators relate to water system variables such as groundwater levels, streamflows, reservoir storage, soil moisture, and snowpack. Hydrological indices include the Surface Water Supply Index (SWSI) (Shafer and Dezman, 1982), and the Palmer Hydrological Drought Severity Index (PHDI) (Karl, 1986). These indicators reflect that hydrological drought usually is slow to develop and persists longer than meteorological drought. For instance, groundwater is usually a later indication of drought conditions and a more conservative indicator for recovering from drought, yet its usefulness may be limited by poor understanding of subsurface conditions and anthropogenic influences. Streamflows can integrate other indicators, such as soil moisture, groundwater, and precipitation, yet can also be heavily influenced by anthropogenic factors, such as development and diversions. Reservoir levels and reservoir storage are easy to measure, yet operating rule curves may complicate assessments of drought conditions. Regarding indices, the PHDI was designed to reflect longer-term hydrological impacts, and the SWSI was developed to address some of the limitations of the Palmer Indices by incorporating water supply information. Both of these indices, however, can be difficult to interpret directly and compare consistently. The various strengths and limitations of common indices will now be examined in greater detail.

A. Precipitation

Precipitation, as a variable, can be transformed into several types of indices, such as Percent of Normal, Deciles, and the Standardized Precipitation Index.

1. Percent of Normal can be useful for analyzing a single region or a single season, yet it is easily misunderstood and gives different values depending on the location and time period. Further, mean precipitation, which is the average amount, usually differs from median precipitation, which is amount exceeded 50% of the time. This is because precipitation tends to be skewed rather than normally distributed. For a positively skewed precipitation distribution, the median is less than the mean, so below-normal (below-average) precipitation is more likely than above-normal precipitation. For instance, in Melbourne, Australia, median precipitation for February is 32.4 mm, but this is only 68.6% of "normal" when compared to the mean (47.2 mm) (AU-CBM, 2003). Using Percent of Normal can make it difficult to link a value of a departure with a specific impact occurring as a result of the departure, and thus to design appropriate drought mitigation and responses (Willeke et al., 1994).

2. Deciles are another approach (Gibbs and Maher, 1967), which can address limitations with the Percent of Normal approach. The long-term precipitation record is divided into tenths of percentiles, called deciles: lowest 20% is much below normal; next lowest 20% is below normal; middle 20% is near normal; next highest 20% is above normal; and highest 20% is much above normal. The method of Deciles was selected for the Australian Drought Watch System because of simplicity, consistency, and understandability over the PDSI (Smith et al., 1993). One challenge, though, is that a long climatological record with consistent observation stations is needed to calculate the deciles accurately. Also, Deciles can be difficult to apply if officials and the public are not familiar with the Decile system.

3. Standardized Precipitation Index (SPI), developed by McKee, Doesken, and Kleist (1993), quantifies the precipitation deficit for multiple time scales, such as for 3-, 6-, 9-, and 12- month prior periods, relative to those same months historically. These different time scales are designed to reflect the impacts of precipitation deficits on different water resources. For instance, soil moisture conditions respond to precipitation anomalies on a relatively short scale, whereas groundwater, streamflow, and reservoir storage reflect longer-term precipitation anomalies.

The SPI is based on a long-term precipitation record, typically at least 30 years, for a desired region, such as a Climate Division. This long-term record is fitted to a probability distribution, such as the Gamma distribution or Pearson III, so that a percentile on the fitted distribution corresponds to the same percentile on a Gaussian distribution (Panofsky and Brier, 1956). That percentile is then associated with a Z-score for the standard Gaussian distribution, and the Z-score is the value of the SPI.

The categories of the SPI, according to McKee et al. (1993), are as follows:

SPI values	Drought Category	Cumulative Frequency
0 to –0.99	Mild drought	16%-50%
–1.00 to –1.49	Moderate drought	6.8%-15.9%
–1.50 to –1.99	Severe drought	2.3%-6.7%
–2.00 or less	Extreme drought	< 2.3%

Advantages of the SPI are that it is standardized, so its values represent the same probabilities of occurrence, regardless of time period, location, and climate. Disadvantages are that the SPI values, the statistical Z-score, may not be intuitive to decision-makers. Also, equal categorical intervals have differing probabilities of occurrence. For instance, the probability differential between an SPI of –1.0 and –1.5 is 9.1% (moderate drought), and between an SPI of –1.5 and –2.0 is 4.4% (severe drought), even though both represent an index differential of 0.5.

B. Palmer Drought Severity Index, Palmer Hydrologic Drought Index (PDSI; PHDI)

The Palmer Drought Severity Index, based on the Palmer Drought Model (Palmer, 1965), has been one of the most commonly used drought indicators in the United States. The PDSI is derived from a moisture balance model, using historic records of precipitation, temperature, and the local available water capacity of the soil. The Palmer Hydrologic Drought Index (PHDI) uses a modification of the PDSI in order to assess longer-term moisture anomalies that affect streamflow, groundwater, and water storage. A primary difference between the PDSI and the PHDI is the calculation of drought termination, using a ratio of moisture received to moisture required to definitely terminate a drought. With the PDSI, a drought ends when the ratio exceeds 0%, if it remains greater than 0% until reaching 100%. With the PHDI, a drought does not end until the ratio reaches 100% (Karl, 1986; Karl et al., 1987).

The PDSI/PHDI are calculated for climate divisions, typically on a monthly basis, with cumulative frequencies representing all months and all climate divisions (Karl, 1986):

PDSI/PHDI	Drought Category	Cumulative Frequency (approx.)
0.00 to –1.49	Near normal	28%-50%
–1.50 to –2.99	Mild to Moderate drought	11%-27%
–3.00 to –3.99	Severe drought	5%-10%
–4.00 or less	Extreme drought	≤ 4%

These PDSI/PHDI values, however, are not spatially and temporally invariant. Cumulative frequencies vary, depending on region and time period under consideration (Karl et al., 1987; Guttman et al., 1992; Soulé, 1992; Nkemdirim and Weber, 1999). For example, the category of "extreme drought," with the overall frequency of ≤ 4%, varies in frequency from less than 1% in January in the Pacific Northwest to more than 10% in July in the Midwest (Karl et al., 1987; Guttman et al., 1992). As another example, the probability of occurrence of "extreme drought" in Virginia varies as follows: CD1 January, 4.17%, CD1 July 2.08%, CD6, January, 3.21%, CD6, July, 1.04% (Lohani et al., 1998).

As regional drought indices, the PDSI/PHDI permit comparisons of drought events over relatively large areas. The Palmer indices also offer a long-term historic record, going back more than 100 years. Yet the Palmer Indices and its water balance model have several limitations (Alley 1984; Karl and Knight, 1985; Karl 1986; Guttman et al. 1992). The Palmer Indices are not particularly suitable for droughts associated with water management systems, because they exclude water storage, snowfall, and other supplies. Human impacts on the water balance, such as irrigation, are also not considered. The values for determining the severity of the drought, and the beginning and end of a drought, were arbitrarily selected based on Palmer's studies of central Iowa and Kansas. The water balance model has been critiqued on several grounds; for instance, soil moisture capacities of the two soil layers are independent of changes in vegetation. The methodology used to normalize the values is only weakly justified on a physical or statistical basis. For instance, for climatic regions with a large interannual variation of precipitation, the statistical measure of normal is less meaningful than other measures, such as the range, median, or mode of the precipitation distribution (Wilhite and Glantz, 1985). The indices are based on departures from climate normals, but without considering variability of precipitation, and tend not to perform well in regions with extreme variability in rainfall or runoff (Smith et al., 1993). Although the Palmer Index is widely applied within the United States, it has little acceptance elsewhere (Kogan, 1995).

C. Surface Water Supply Index

The Surface Water Supply Index (SWSI), pronounced "swazee," was developed by Shafer and Dezman (1982) to address limitations of the Palmer Indices and incorporate water supply data, such as snow accumulation and melt, which are important in the western U.S. The index is based on four components: snowpack, streamflow, precipitation, and reservoir storage. Monthly data for each component are analyzed according to probabilities of occurrence, combined into overall index, and weighted according to their relative contributions to surface water in the basin. A modified SWSI (Garen, 1993) provides stronger statistical foundations to the index, with drought categories and cumulative frequencies as follows:

SWSI	Drought Category	Cumulative Frequency (approx.)
–2.00 to 0.00	Mild drought	26%-50%
–3.00 to –2.00	Moderate drought	14%-26%
–4.00 to –3.00	Severe drought	2%-14%
below –4.00	Extreme drought	< 2%

Advantages of the SWSI are that it represents water supply conditions unique to each hydrological area, such as regions heavily influenced by snowpack. Limitations are that changing data sources or water supply sources requires that the entire index be recalculated to account for changes in the frequency distributions and the weights of each component. For instance, discontinuing any station means that new stations need to be added to the system and new frequency distributions need to be determined for that component. Thus, it is difficult to maintain a homogeneous time series of the index. If extreme events are beyond the historical time series, the index will also need to be recalculated. Further, because the index is unique to each basin, comparisons among basins or regions are limited (Doesken et al., 1991).

Having reviewed some common indicators, the next sections will provide guidance in their development, implementation, and evaluation. Although the purpose of this chapter is not to review all possible indicators and triggers, the use of key examples will nonetheless illustrate important and more general concepts. For additional details on specific indicators and definitions, see, e.g., Dracup et al. (1980), Fisher and Palmer (1997), WMO (1992), and Heim (2002).

II. Multiple Indicators and Triggers: Challenges and Solutions

A. Typical Problems with Indicators and Triggers

Because drought can be characterized in many different ways, and because single indicators often prove inadequate for decision makers, multiple indicators and triggers can be useful. But challenges arise in trying to combine multiple variables and values in a drought management plan. Indicator scales may be incomparable, and trigger values may be statistically inconsistent.

Comparison of the three index scales above illustrates common problems with indicators and triggers in drought plans. These problems exist not only for values of indices (e.g., SPI, PDSI/PHDI, SWSI), but also for values of indicators (e.g., total monthly precipitation, average monthly streamflow, average monthly reservoir levels), for several reasons:

First, drought categories (levels) are inconsistent in terms of cumulative frequency. For instance, "severe drought" occurs 4.4% of the time for the SPI, 5% for the PDSI/PHDI, and 12% for the SWSI. Second, index values are difficult to interpret directly (what does a –1.5 index value mean?), and imply different probabilities of occurrence for different indicators. A value of "–1.5" represents a cumulative probability of 6.7% for the SPI, approximately 27% for the PDSI/PHDI, and 32% for the SWSI. Third, as we saw earlier, the values of the indicator can vary, in terms of frequencies, depending on time and location (with the exception of the SPI). Finally, because of these inconsistencies, trying to use more than one indicator in operational drought management can cause confusion and can impede effective and timely drought response.

Further, an evaluation of state drought plans in the U.S. revealed wide variation in quality concerning indicators and triggers. A plan usually characterized one of four types, representing incremental degrees of detail: (1) A plan mentions indicators, but without details on how these indicators are measured or used. For instance, an indicator of "precipitation" is mentioned, but not whether precipitation is measured by the SPI, Deciles, or another approach. Also lacking are triggers and drought plan levels. (2) A plan provides some guidance on indicators, but without information on trigger values and corresponding drought levels. For instance, a plan may say that "streamflows" are monitored by the "monthly mean values" but those values associated with drought levels and responses are not specified. (3) A plan provides indicators and triggers, typically raw values of the indicators, which often lack statistical consistency. For instance, a plan may use the SPI-6, PHDI, and streamflows, but these indicator values have different probabilities of triggering each drought plan level. Thus, some indicators influence triggering more than others. Even if plans specify how the triggers may be combined, that combination method may also be statistically inconsistent. (4) A plan contains details on indicators and trigger values, plus triggers and associated drought levels are statistically comparable. One way to accomplish this is through a percentile-based approach, which is described in the next section.

B. Percentiles for Drought Indicators and Triggers

A solution for using multiple and often statistically inconsistent indicators in a drought management plan is to transform all indicators, triggers, and drought levels to a scale based on percentiles. Then trigger values are associated with the percentiles defining the drought levels. The usefulness of this approach becomes apparent when trying to compare, combine, and choose among drought indicators and trigger values. It offers a consistent and equitable basis for evaluation, ease of interpretation and application to water management decisions, such as by relating triggers to familiar concepts as return periods and probabilities of occurrence.

Indicators and indices can be transformed to percentiles by fitting a distribution to the data (such as a Gamma distribution or Pearson III for precipitation), or by developing an empirical cumulative distribution function (ECDF) using ranking algorithms, plotting positions, or other cumulative probability estimators (Harter, 1994). The drought plan triggers are then based on percentiles instead of raw indicator or index values.

For instance, suppose the PDSI will be used as an indicator in a drought plan. Rather than specify a single value of the PDSI (such as –1.5) for triggering a drought level (such as Moderate Drought) for all locations and time periods, instead specify either a percentile (such as 0.20) or a PDSI value associated with that percentile for each location and time period (such as 0.20 being associated with a PDSI value of –1.3 for January for Climate Division 1, a value of –1.2 for February for Climate Division 1, and so forth for each month for each climate division).

To do this, stratify the long-term record of PDSI data by location (such as climate division) and time period (such as month), or in subsets of data that approximate stationarity. Then develop an ECDF for each stratified dataset, using a method such as: $p(x_i) = (i) / (n+1)$, where $p(x_i)$ is the cumulative probability estimator, x_i is the value of the drought indicator, i is the rank of the order statistic x_i, where i = 1, ..., n (in order from smallest to largest values), and n is the number of data values. Next, select the desired percentile for triggering a certain level of a drought plan (such as the 20th percentile for Moderate Drought). Using each ECDF, extract or extrapolate the PDSI value associated with that percentile. A similar approach can be used for other indicators, whether based on a theoretical or empirical distribution, such that each trigger value associated with each drought level is statistically consistent (Steinemann, 2003).

C. Example: The U.S. Drought Monitor

One example of a product developed from multiple indicators is the weekly U.S. Drought Monitor product (Hayes et al., 2004, Chapter _). This product was originally released in August 1999, and was developed to provide a weekly assessment of drought conditions across the United States on a general scale. What makes the Drought Monitor unique is that it incorporates a variety of quantitative indicators and is also adjusted based on qualitative information from a network of local "experts" around the country. The quantitative indicators include the Palmer and Standardized Precipitation Indices, streamflow information, a soil moisture model, precipitation totals for various time periods, and a vegetation index derived from satellite data. Although some of this information is available in percentiles, the map is based on a subjective combination of this information and the qualitative indicators.

An advantage of the Drought Monitor is that the map provides a "big picture" assessment of drought conditions across the country for the public, media, policy makers, and others interested in a relatively simple representation of the overall drought situation. It also recognizes that because of the complexity of drought conditions and impacts, it is important to make adjustments to the drought depiction based on the qualitative information. The network of local experts provides a crucial accountability process to make sure the Drought Monitor map is representing drought conditions at this larger scale. The Drought Monitor, however, is not meant to capture local drought conditions, and this is a major limitation. It should not be used for making decisions at smaller resolutions representing counties, for example.

III. Developing and Evaluating Indicators and Triggers

Based on a systematic review of state and local drought plans, and interviews with water officials, a set of considerations and criteria for indicators and triggers has been developed:

A. Considerations for drought indicators and triggers

1. Suitability for drought types of concern: An indicator needs to reflect the type of drought of concern, including aspects of water demands, water supplies, drought vulnerabilities, and potential impacts. Because drought depends on numerous factors, no single indicator is likely to cover all types of drought. In choosing indicators, a first consideration is that they should make sense for the context. For instance, the Palmer Indices may not be appropriate as sole indicators for managed water systems because they do not incorporate reservoir storage. Reservoir storage, on the other hand, may not be appropriate as a sole indicator for agricultural areas that use only groundwater for irrigation.

2. Data availability and consistency: The performance of an indicator depends on the availability and quality of the data. Many indicators may be conceptually attractive, but are difficult, costly, unreliable, or impractical to generate, so they may not be appropriate for use. When choosing an indicator, consider the following questions: Are the data readily available? Is the indicator straightforward to calculate? Are the data trustworthy? Will the analytic expense justify the decision-making value? Does the value of the indicator vary, depending on the source of data or method of calculation? Is there a consistent long-term record, and will the data be consistently generated in the future? For this reason, many drought plans use indicators based on data that are already collected, subjected to quality control, and consistently reported, such as by a government agency.

3. Clarity and validity: Indicators and triggers need to be readily understood and scientifically sound, so that drought decisions can be made and defended on the basis of them. In addition, they should be tested before a drought, and evaluated after a drought, to see how well they perform. A pre-drought assessment could involve generating historic sequences of triggers, and comparing them to human assessments of the drought triggers that should have been invoked during that time. Another approach is to conduct virtual drought exercises with stakeholders and decision makers, using different sets of triggers and comparing management responses. A post-drought evaluation could involve a similar process of comparing actual triggers invoked to triggers that would have provided the greatest decision-making value.

4. Temporally and spatially sensitive: Indicators and triggers need to consider both temporal and spatial variability. This is because indicator levels that imply drought conditions for one time

period or one region could imply wet/normal conditions for another time period or another region. For instance, “monthly total precipitation of three inches” could imply dry conditions in early spring but wet conditions in late summer, and imply dry conditions for a mountainous area of a state, but wet conditions for a desert area of the same state.

5. Temporally and spatially specific: Indicators and triggers also need to specify the temporal and spatial scale of analysis. Temporally: Indicators need to be associated with a specific time period of calculation. For instance, the SPI-6 calculates the precipitation anomaly for a prior six-month period relative to that same six-month period historically. Triggers also need to be associated with a time period for determining drought levels and responses. An example would be the "SPI-6 below –1.5 for two consecutive months would invoke Level 2 drought." In this case, the indicator's time period would be the six prior months, and the trigger's time period would be two consecutive months. Spatially: Indicators need to define the scale of analysis, such as a climate division or hydrological basin for precipitation, soil moisture, and snowpack. For other indicators, such as groundwater, reservoir levels/storage, and streamflows, the spatial scale may be implicitly defined by the selection of a specific well, reservoir, or gauging station. Indicators should, nevertheless, specify the spatial scale of drought that they seek to represent, such as a set of streamflows to represent drought within a certain river basin. Triggers need to define the spatial scale of implementation of drought responses, such as the use of three groundwater wells to trigger drought responses within an entire climate division or county. Even a trigger such as a reservoir level does not necessarily imply that the spatial scale of response is that reservoir, but instead could trigger responses, such as water use restrictions, for an entire state.

6. Drought progressing and receding: Indicators and triggers should be defined for both for getting into a drought, and getting out of a drought, at each level of a drought plan. Even though many drought plans assume that the progressing triggers can be reversed to function as the receding triggers, that may not be desirable from a drought management perspective. There may be different management goals for going into a drought versus going out of a drought. For instance, it may be important to implement water use restrictions as soon as drought conditions start developing, but to be more conservative and wait to lift restrictions when drought conditions appear to be recovering. Trigger examples would be to invoke a drought level after two consecutive months in a certain or more severe level, but to wait to revoke drought restrictions until after four consecutive months in a certain or less severe level.

7. Statistical consistency: Triggers need to be statistically consistent with drought levels, as well as with other triggers in a drought plan. As we saw earlier, the probabilities of occurrence of the Palmer Index were not consistent among drought levels, and varied according to time and locations. Moreover, the index scales of the PDSI/PHDI, SPI, and SWSI were not consistent with each other. For instance, the value of –1.5 had different cumulative frequencies for each index. From the perspective of a decision maker, the choice of drought indicators may be difficult, but that difficulty will be compounded if indicator scales and trigger values cannot be validly compared and combined in drought decision-making.

8. Linked with drought management goals: Indicators need to be linked with drought management and impact reduction goals, and trigger levels should be set to invoke responses at

times and stages that are consistent with these goals. For instance, triggers can be set so that a certain percentile will invoke responses that will produce a desired percentage reduction in water use. Drought indicator performance should also be considered; for instance, the degree of responsiveness or persistence desired in an indicator. Some water managers may prefer an indicator that responds quickly to short-term anomalies, such as the SPI-3, in order to take early action to reduce drought impacts, whereas other water managers may prefer an indicator with greater stability and persistence, such as the SPI-12, in order to avoid frequent invoking and revoking of drought responses. Intermediate indicators, such as the SPI-6, can provide elements of both.

9. Explicit combination methods: Drought plans often rely on multiple indicators. But a question arises: If multiple indicators are used, how are they considered or combined to determine a final drought level? In other words, multiple triggers may suggest different drought levels, so methods need to be specified for combining triggers and determining the final level. These can include quantitative methods and criteria such as: the most severe of the indicators, at least one of the indicators, or a majority of indicators. These can also include qualitative methods, such as convening a drought committee to determine when to implement responses. Whether quantitative or qualitative, the methods for calculating indicators should be specified, as well as the process for combining opinions or weighting individual data for an overall indicator.

10. Quantitative and qualitative indicators: Indicators can be based on quantitative data and qualitative assessments, or both. Although many drought plans center on quantitative indicators, the importance of qualitative expertise should not be overlooked. A human expert is able to consider and synthesize numerous indicators, applying years of experience and expertise to assess drought conditions. Perhaps even more important is the recognition that indicators and triggers are meant to help decision makers, not replace decision makers. A drought plan is but one source of information, and other considerations will likely be important for decision-making.

B. Checklist for Indicators and Triggers in a Drought Plan

In addition to these criteria and considerations, a checklist is provided. Note that these pertain only to the indicators and triggers portion of a drought plan, and that many other drought plan components are important, such as communication and coordination among agencies responsible for monitoring the indicators and implementing the responses if they are triggered. Nonetheless, this list is intended to offer a straightforward set of metrics to check.

1. Indicators specification and consistency

a. Indicators definition - Whether each indicator is defined and specified.

b. Indicator calculation method - Whether each indicator's calculation method is provided.

c. Spatial scale definition - Whether the spatial scale for monitoring and analyzing the indicator is defined (such as a particular Climate Division for the SPI-6).

d. Spatial sensitivity - Whether the indicator is sensitive to spatial variability, such as wetter regions in the mountains and drier regions in the desert.

e. Temporal scale definition - Whether the temporal scale for monitoring and analyzing the indicator is defined (such as a prior six-month period for the SPI-6).

f. Temporal sensitivity - Whether the indicator is sensitive to temporal variability, such as wetter months in the early spring, and drier months in the late summer.

2. Triggers and drought levels specification and consistency

a. Definition of drought levels - Whether there are explicit drought levels such as “level/stage/phase 0, 1, 2, and 3” or “normal, moderate, severe, extreme.”

b. Definition of triggering thresholds for each indicator - Whether quantitative indicator thresholds (i.e., triggers) are defined for each drought level.

c. Spatial scale of trigger - Whether triggers specify the spatial scale for implementation. Consider the trigger: “SPI-6 less than –1.5 for two consecutive months within Climate Division 1 will invoke Level 2 drought responses for Counties X and Y.” Here, the spatial scale for the trigger would be Counties X and Y, even though the spatial scale for the indicator is Climate Division 1.

d. Temporal scale of trigger - Whether triggers specify the temporal scale for implementation. Consider the trigger: “SPI-6 less than –1.5 for two consecutive months within Climate Division 1 will invoke Level 2 drought responses for Counties X and Y.” Here, the temporal scale for the trigger would be two consecutive months, even though the temporal scale for the indicator is the prior six months.

e. Statistical consistency among indicators/triggers thresholds/drought levels - Whether the triggers (one or more) are statistically consistent with each other and with drought levels.

f. Explicit triggers for "drought progressing" - Whether indicators/triggers are defined for moving from a less severe drought level to a more severe drought level.

g. Explicit triggers for "drought receding" - Whether indicators/triggers are defined for moving from a more severe drought level to a less severe drought level.

h. Explicit method to combine indicators - Whether objective or subjective methods for using and combining multiple indicators/triggers are specified.

IV. Conclusion

Indicator and triggers are essential to drought preparation and response, yet they often lack needed attention in drought plans and planning processes. This chapter examined the most common indicators and triggers, and provided guidance for their development and evaluation. What makes a "good" indicator or trigger depends not only on its scientific merits, but also on its value to decision-makers.

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